MEMORANDUM

To: **Emily Anderson, Wild Salmon Center**

From: **Cameron Wobus, PhD., Lynker Technologies, Robert Prucha, PhD., Integrated Hydro Systems**

Subject: **Comments on Pebble Project Final EIS**

Date: **August 19, 2020**

Lynker Technologies, LLC (Lynker) was retained by the Wild Salmon Center to provide technical comments regarding the hydrologic impacts described in the Pebble Project Final Environmental Impact Statement (FEIS), with an emphasis on how the new draft addresses previous critiques raised by cooperating agencies and other experts. Tens of thousands of pages of new documents have been entered into the public record since the draft EIS was filed; it was impossible to review all of these documents in the time allotted. Accordingly, we focused our review on the main text of the FEIS related to tailings failures, water management and groundwater modeling, as well as the following documents that are most directly related to our expertise and previous work:

- Tailings failures
  - Appendix K4.27 Spill Risk and supporting documentation
  - Responses to comments (Appendix D) pp. 247-248
  - AECOM (2019) Memorandum re: TSF stability analysis
  - ADNR (2020) Comments on PFEIS
- Water management and water balance
  - RFI 138, Watershed model water balance
  - Pebble Project Hydrometeorology Report
  - RFI 109g, Comprehensive Water Modeling System
  - Responses to comments (Appendix D) pp. D-103-105, 123, 231
  - Lynker (pp. D-247-248)
- Groundwater modeling results
  - Numerical Groundwater Flow Model Report (BGC, 2019)
  - Pebble Project: Comparison of Numerical Groundwater Flow Models (BGC 2019b)

Based on our review, we reach the following key conclusions:

- The conclusion that the risk of tailings dam failure is too remote to warrant consideration in the FEIS is arbitrary, and is inconsistent with the information contained in the final report and in the public record. In fact, the **USACE's own third party contractor and the Alaska Dam Safety Program each question whether the conceptual tailings facility design will work.** Given substantial gaps in the conceptual TSF designs, the FEIS should explicitly describe not only the impacts of a TSF failure but also the mitigation and bonding that would be required to clean up from such an event.
- The FEIS still falls far short of demonstrating a fundamental understanding of the baseline hydrologic system, and therefore does not support quantification of mining and post-mining impacts on the system. **Specifically, the components of the "Comprehensive Water Modeling System" do not simulate the fully coupled, physically-based hydrologic processes that the mine would affect, and therefore cannot be used to predict the magnitude, duration, or extent of hydrologic impacts from the Pebble Mine.**

- PLP developed a new groundwater model since the DEIS, which has not been made available for public comment. This new model does not accurately represent the coupled groundwater-surface water system at the proposed mine site, relies on arbitrary values for key parameters, and fails to assess uncertainty in model predictions of mine impacts using standard methods. As a result, **the new groundwater model substantially mis-represents the full range of equally-likely hydrologic impacts of the proposed project.**
- Water treatment system failures, including failure of the water treatment plant during operations or of the perpetual treatment systems after closure, are not adequately considered in the FEIS. For example, since pumping and treating the pit after closure is proposed in perpetuity, **a failure of this perpetual treatment system must be considered reasonably foreseeable and its impacts should be included in the FEIS.**

Our major comments are summarized in the sections that follow, organized by the major themes described above.

1. The Tailings Management Plans are Too Incomplete to Dismiss Tailings Dam Failure Risk: The FEIS Should Evaluate Tailings Failure Impacts

As multiple cooperating agencies and experts have noted on the record, one of the most significant environmental risks posed by the Pebble Mine is that of a tailings dam failure (USEPA, 2019; Lynker, 2019a; ADNR, 2020). If a more robust tailings failure analysis had been considered in the FEIS, it would most likely find results similar to what the Lynker (2019a) study found, which is that any reasonable scenario of a tailings dam breach would send tailings dozens of miles downstream, with major, long term, adverse impacts to the Bristol Bay ecosystem. USACE's critique of the Lynker (2019a) model in Appendix K4.27 ignores the detailed results of that model, and instead relies on the unfounded assumption that a conceptual, unproven tailings design cannot fail.

> The FMEA [failure modes and effects analysis] considered large-scale catastrophic releases such as what would be caused by a full breach of one of the embankments. The probability of a full breach of the bulk or pyritic TSF tailings embankments was assessed to be extremely low (i.e., worst-case). (FEIS, p. 4.27-104)

Thus, rather than addressing the potential environmental consequences of a bulk tailings dam failure as summarized by Lynker (2019a), the FEIS relies on the FMEA as evidence that such a failure simply cannot occur. This is despite the fact that an FMEA is not the proper tool for risk assessment, as underscored by the Alaska Department of Natural Resources (ADNR) in its cooperating agency comments:

> FMEA's are subjective and prone to significant cognitive bias and other forms of bias and are reportedly unreliable for formal risk assessment (Oboni, et.al. 2012; Oboni, et.al. 2013; Thomas, et.al., 2014). Using the FMEA "to assess the likelihood of a spill and the severity of potential environmental impacts" as described in paragraph 3 is a novel application of the FMEA process. Subjectively categorizing the likelihood of failure modes as "relatively low", "extremely low", "extremely unlikely" or other terms, then using these assignments for extrapolating probabilities for selecting failure scenarios for evaluating potential environmental impacts or making decisions should be conducted with <u>extreme</u> caution and include clearly stated caveats (ADNR 2020, p. 4; emphasis included in original ADNR comments)

As summarized in the remainder of this section, dismissing the potential impacts of a TSF failure because the probability of failure is "extremely low" is flawed, and is unsupported by the information in the FEIS. Specifically, the FEIS explicitly states that the applicant is ignoring best available technologies for bulk tailings disposal, and the USACE's own contractors and the ADNR dam safety branch both question whether the conceptual-level design for the bulk tailings facility can function as planned. Furthermore, multiple experts including ADNR have questioned the feasibility of the closure plan for the pyritic TSF. The pyritic TSF is therefore likely to remain on the landscape much longer than assumed in the FEIS, so the risk of failure for that impoundment, too, will be much higher than the FEIS suggests. As a result, the conclusions reached in the FEIS regarding the probability of a tailings failure are arbitrary, and unsupported by available data. Lynker (2019a) developed a tailings dam failure model using industry-standard modeling tools; site-specific data from the Pebble Limited Partnership regarding the physical characteristics of the proposed "thickened tailings" (Knight Piesold, 2018a); and a broad range of scenarios ranging from a 10% to a 60% tailings release. These tailings failure modeling results are relevant to the environmental impact analysis in the FEIS, and should be considered or replicated, but not ignored.

1.1 The Bulk Tailings Facility Design Ignores Best Available Technologies

Following the Mt. Polley tailings dam failure, the Mount Polley Independent Expert Engineering Review Panel (IEERP) provided a specific set of recommendations for minimizing the risk of future failures. Although the FEIS acknowledges some of the basic principles of minimizing tailings failure risk, the spill risk discussion in Appendix K4.27 also acknowledges that the conceptual-level bulk tailings storage design does not incorporate any of the specific best available technology recommendations from the IEERP:

> Best available technology (BAT) principles suggested following the Mount Polley dam failure (Morgenstern et al. 2015) include eliminating or minimizing surface water in TSFs and promoting unsaturated conditions in tailings through drainage provisions. (FEIS, p. K4.27-3)

While limiting water is indeed an overarching principle of safe tailings storage, Morgenstern et al. (2015) do not include "thickened tailings" – the approach advanced by the Pebble Mine proponents – among the list of BAT for safe storage of tailings. In fact, each of the specific BAT described by Morgenstern et al. (2015) is systematically rejected in the remainder of Appendix K4.27:

> The Mount Polley Independent Expert Engineering Review Panel (IEERP) also stated that placing tailings in mined-out open pits is the most direct way to reduce the number of TSFs subject to failure (Morgenstern et al. 2015). The Applicant has proposed this for pyritic TSF. **This was also considered for the bulk TSF as part of the National Environmental Policy Act (NEPA) Alternatives Analysis (Appendix B), but was ruled out as not practicable for the Pebble Project.** (FEIS, p. K4.27-3,4)
>
> The Mount Polley IEEIRP also stated that "surface storage using filtered tailings technology is a prime candidate for BAT" (Morgenstern, et. al. 2015). This alternative of filtered tailings (also called dry stack tailings) was also put forth for consideration as part of the NEPA Alternatives Analysis process (Appendix B). **However, dry stack/filtered tailings were considered not practicable for the Pebble project.** (FEIS, p. K4.27-3,4)
>
> The BAT objective of reducing water in the tailings could also be achieved by compacting tailings to drive out excess fluid from the pore spaces between the tailings particles, and reduce the ability of tailings to flow in the event of a dam failure. Luino and De Graff (2012) conclude that tailings that are deposited as a slurry and not able to drain their excess fluid will tend to maintain a state of saturation under their self weight. This would result in limited additional consolidation over time and the continuation of a lower tailings density. Tailings can be mechanically compacted, which is not feasible for slurry or thickened tailings, but is routinely performed on dry stack tailings. **Compaction of tailings is considered not practical for the bulk TSF.** (FEIS, p. K4.27-4)

As summarized below, the applicant's proposed alternative – using "thickened" tailings – remains at a highly conceptual level, and its ability to mitigate tailings failure risk is unsupported by available data. Thus, while the FEIS dismisses the possibility of a tailings failure on the grounds that the TSF design will be safe, this conclusion relies on an unproven, conceptual-level design rather than any proven technologies.

Summary

- The FEIS tailings management plans systematically reject the BAT recommendations for safe tailings disposal as described by the Mt. Polley IEERP. Instead, the PFEIS relies on an unproven, conceptual-level design for tailings management.

Recommendation

- If the preferred alternative is designed to minimize the environmental impacts of resource extraction, it should follow best practices for tailings management to minimize spill risk. A tailings management plan that systematically ignores BAT recommendations cannot represent the least environmentally damaging practicable alternative.

1.2 The Bulk Tailings Facility Design is Flawed

In order for the tailings to de-water and for the bulk tailings facility to become stable over time, the facility needs to be designed in a way that allows water to drain. The FEIS and available RFIs describe how the tailings are intended to behave to ensure tailings and embankment stability:

> The bulk TSF would include basin and embankment underdrains to help maintain a reduced phreatic surface in both the tailings and the embankment [...] Drainage provisions would be intended to promote unsaturated conditions, but the phreatic surface could remain higher throughout mine operations, as discussed above. [...] **Adequate drainage would be critical to the success of the bulk TSF design.** (FEIS p. K4.27-8)
>
> The slurry tailings discharge as envisioned for the Bulk TSF results in deposition of the coarse fraction of tailings nearest to the discharge point and the finer tailings extending further into the facility. **Maintaining the coarse fraction of the tailings beach against the embankment and implementation of appropriate filter relationships between the embankment materials and tailings beach will allow for the TSF to operate as a drained facility.** (RFI 008h, p. 10/19)

As summarized in these two passages, the stability of the conceptual-level TSF design requires that the tailings are allowed to drain. This in turn requires that the tailings segregate into coarse and finer fractions to ensure that coarser, more permeable material is deposited against the impoundment. The problem is that PLP has no data to support their assumption that the tailings will actually segregate into coarse and fine fractions. They simply state that they are "expected to" do so, with no supporting citation to back this assumption up:

> Tailings deposition and pond water would be managed to allow the continual development and maintenance of a tailings beach behind the bulk TSF main embankment. **This would serve to protect the dam from seepage pressure that could reduce stability** (Knight Piésold 2018a, 2019o; PLP 2018-RFI 006; RFI-008f; PLP 2019-RFI 006c). Tailings are expected to segregate following slurry deposition into three grain size zones (coarse, transition, and fine tailings units), with coarse tailings deposited closest to the spigots and fine tailings in the center of the impoundment (FEIS, p. K4.15-11)

Figure is an illustration of the tailings segregation zones as currently conceptualized in the FEIS. As drawn, this highly idealized cartoon suggests that these segregation zones will be thousands of feet long, with coarse, transition and fine tailings in discrete packages.

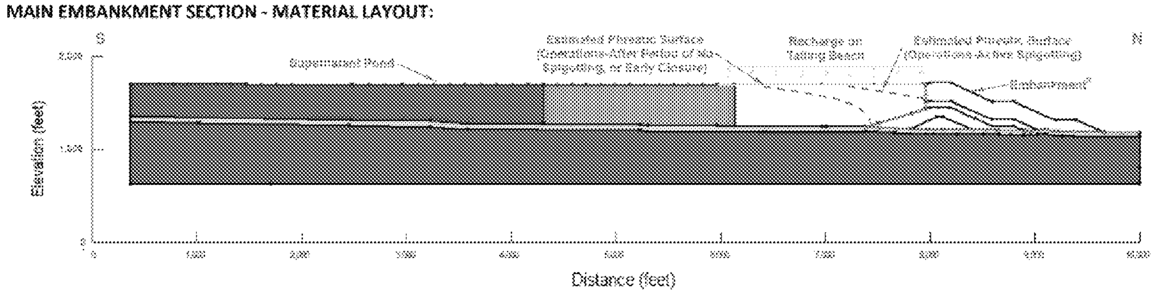

Figure 1. Conceptual level drawing of tailings in bulk TSF with coarse (yellow), medium (orange) and fine (tailings) segregated into ~1000 ft long parcels. Source: FEIS Figure K4.15-3

This conceptual layout was used to support "conceptual-level" tailings dewatering and stability analysis as summarized in the remainder Appendix K4.15 of the FEIS. Unfortunately, there is no physical sedimentation process that would allow this type of segregation to occur naturally, particularly from thickened tailings. More likely, the tailings would settle as a mixed grain-size ("well-graded") deposit with much lower permeability than assumed in the tailings stability analysis. This fundamental design flaw was pointed out by USACE's third party contractor, AECOM, while the EIS was being finalized:

> The description of sedimentation processes in the RFI response that occur with conventional tailings deposition is usually true for slurry tailings, but not necessarily for thickened tailings, which do not segregate like slurry tailings do. MEND (2017) indicates that "**Thickened tailings may be non-segregating, producing a tailings product with potentially low hydraulic conductivity and high moisture retention capacity….** Consistency will depend on the variability of the tailings properties." **Thus, the summary of expected particle size sorting behavior based on Vick (1990) in the RFI response is incomplete and misleading."** (AECOM 2019, p. 1)

The implications of the thickened tailings potentially being "non-segregating" were also explicitly acknowledged in the FEIS tailings stability analysis:

> A well-graded, non-segregated, low-permeability, thickened tailings deposit could result in significantly different predictions about seepage performance. For example, a reduction in the K value of the coarse tailings by an order of magnitude, and reduction in the length of this unit by 800 feet, resulted in 30 to 40 percent lower seepage rates compared to the initial case (Table K4.15-4), with potentially related increases in phreatic surface elevations. (FEIS, p. K4.15-25)

In other words, while the main text of the FEIS suggests that the possibility of tailings failure is "extremely low" because it assumes the facility will drain and stabilize over time, other sections of the FEIS and files in the public record simultaneously acknowledge that the tailings probably will not drain as intended. This would result in a higher water level ("phreatic surface") in the bulk TSF, with implications for tailings stability. This is clearly stated in the expert review of the FEIS by AECOM engineers:

> As discussed in Section 2.3, one of the contributing factors of the recent failure of the Fundão Dam at Samarco Mine in Brazil were operational problems with achieving the planned tailings deposition and drainage objectives in silty versus sandy tailings at this flow-through mine (Morgenstern et al. 2016). **We remain concerned that there are uncertainties as to whether the 55 percent thickened tailings planned by PLP would segregate enough to promote reduction of the phreatic surface near the embankment, which translates to uncertainties regarding the effect of tailings segregation on embankment stability.** (AECOM 2019, p. 2)

The Alaska Department of Natural Resources, which houses the Dam Safety Program, expressed similar concerns in its cooperating agency comments sent on March 23, 2020:

> Thickened tailings will develop beaches and perform differently from whole slurry tailings such as 25% solids/75% water [...] and may not segregate to drain more freely as assumed. The consolidation time required to gain any improvements in strength are not described. **A well graded, unsegregated, low-permeability, thickened tailings deposit could result in significantly different predictions about stability and seepage performance than described for the "flow-through structure" and the apparent inconsistency with segregated tailings shown in Figure K4-15.3 should be resolved** (ADNR, 2020).

As summarized above, both the FEIS and comments from AECOM and ADNR raise significant doubts about the ability of the bulk tailings to drain, and thus stabilize through time.

Summary

- Criticisms raised by USACE and ADNR, as well as PLP's own modeling results, demonstrate that the majority of the bulk tailings are likely remain saturated throughout operations and post-closure.
- Under the saturated conditions that are likely given the current conceptual designs, the stability of the bulk tailings facility is questionable. The bulk tailings facility is therefore likely to pose the same level of failure risk as historical tailings dams.

Recommendation

- Because the conceptual-level design of the bulk tailings facility is unlikely to perform as described, the long-term risk posed by the bulk tailings facility is not "extremely low" and should be considered in the FEIS as a reasonably foreseeable environmental impact of the Pebble Mine.

1.3 The FEIS Lacks Key Data to Support the Bulk Tailings Design

The FEIS arbitrarily dismisses the risk of a tailings dam failure as "extremely low", based on an assumption that the tailings facility will behave as described in a conceptual-level model of an unproven design. However, USACE currently has no data to support this conceptual-level design, and has instead deferred all tailings testing and designs until a later date:

> The tailings testing program, which is expected to be completed during the preliminary design phase of the Alaska Dam Safety Program, will include index testing to enable geotechnical classification of the materials, slurry settling, air drying, consolidation and permeability testing to determine the characteristics the tailings. [...] **Results from this testwork will be used to validate the sensitivity analyses and material parameters used in the seepage analysis completed to date** (RFI 008h, p. 10/19)

The lack of data to substantiate the claim that the tailings are "expected" to drain creates a fundamental uncertainty in the TSF embankment stability analysis, which the FEIS does not resolve. Instead, the FEIS defers this analysis as far into the future as the first year of operations:

> There are three areas of uncertainty with respect to embankment static stability at the present level of design: 1) the extent that the thickened tailings would segregate to promote a deeper phreatic surface near the embankment; 2) the extent that pore pressures in the newly placed, potentially soft and loose tailings would reduce sufficiently to provide a stable upstream slope of the first raise [...] **These uncertainties need to be resolved during the final design process and early during the first year of operations to avoid the potential of a possible deeper failure surface up to the depth of the lowest centerline raise, resulting in the possibility that more of the centerline part of the embankment below just the most recent raise could slide into potentially undrained tailings, setting the mass in motion with**

adverse consequential effects on the TSF in a downstream direction. (FEIS, p. K4.15-28,29)

Thus while the FEIS prominently dismisses the risk of a tailings failure in its executive summary, it simultaneously acknowledges that 1) there are large uncertainties in the tailings storage facility designs; and 2) the potential consequences of the conceptual-level design being wrong include a complete failure of the bulk TSF.

The lack of data to support the tailings facility design creates potentially significant problems for the mine permitting process. At best, deferring the tailings testing to a later date leaves open the possibility that the tailings will behave as AECOM (2019) and ADNR (2020) have warned, which means that the tailings impoundment will not function as a "flow through" facility. This would require a complete overhaul of the tailings design, the water management system, and potentially many other components of the proposed mine operation. At that point, key conclusions of the EIS would be invalid, and the EIS would need to be repeated to ensure that the permitting process accurately considers all environmental risks of the project. At worst, deferring the tailings testing to "early in the first year of operations" could lead to a potential TSF failure, with substantial downstream impacts such as those already documented by Lynker (2019a).

Summary

- The applicant has not conducted enough testwork of its tailings to support the conclusions in the FEIS regarding tailings hydraulic properties. Consequently, the FEIS conclusions regarding tailings stability and safety are not defensible.
- Rather than responding to multiple concerns in the public record regarding the stability of the bulk tailings facility, the FEIS recommends that remaining uncertainties be resolved during final design and even during the first year of operations.

Recommendation

- The applicant should complete the tailings testwork and revise the conceptual-level tailings design to account for the findings of that testing. These results should be incorporated into a revised FEIS.
- The FEIS cannot dismiss the risk of a bulk tailings facility failure without the backing of sound science. Uncertainties and data gaps must be addressed before concluding that there is essentially no risk of a tailings dam failure.

1.4 The Risk of a Pyritic TSF Failure Risk Cannot Be Dismissed Because the Pyritic Tailings Management Plan is Not Practicable

A pyritic TSF failure could be even more damaging to the Bristol Bay ecosystem than a bulk TSF failure, because the material stored in that impoundment will be substantially more toxic than the material in the bulk TSF. Lynker (2019b) modeled a series of pyritic TSF failures, and showed that under a range of plausible failure scenarios on the northern embankment, the pyritic tailings would overtop the water management pond and continue downstream into the North Fork Koktuli watershed.

Throughout both the draft and the final EIS, however, the risk of a failure of the pyritic TSF is dismissed because the applicant proposes to place the pyritic tailings back into the pit following closure:

> Several years after the close of mine operations, the pyritic tailings would be pumped into the open pit, which would then be allowed to fill with water, so that the pyritic tailings would be permanently stored sub-aqueously. Perpetual storage in the pit would reduce the potential for a spill of pyritic tailings after the close of operations (FEIS, p. 4.27-94)

It is true that the risk of a pyritic TSF failure would decrease if those tailings were removed and placed in the bottom of the pit. However, as pointed out by ADNR in its cooperating agency comments, that closure plan would be foolish from a business standpoint, as it would render nearly 90% of the Pebble deposit un-mineable; and it would also be technically challenging due to the nature of the material:

Moving the content of the pyritic Tailings Storage Facility (TSF) to the pit at closure does not appear to be reasonable, practicable or safe, for the following reasons:

> 1. Filling the pit with tailings precludes the opportunity to exploit additional resources known to exist at Pebble. Well-established precedence in the mining industry is to conduct significant "condemnation" drilling before constructing permanent features that would restrict access to potentially viable ore bodies...
>
> 2. [...] The closure plan calls for moving the tailings to the pit. This may not be practicable based on the definition from the 404(b)(1) guidelines as described in the second paragraph of Chapter 2 because this would require the material to be handled more than once which adds cost and may represent significant technological challenges [...] Furthermore, removing the tailings with heavy equipment and trucking may not be safe because traffic and excavation on the relatively loose, saturated tailings deposit would be problematic for operations despite consolidation (ADNR, 2020 p. 3).

If placing the pyritic tailings into the pit is not a reasonable or practicable solution to long-term risk management, then the pyritic TSF will remain a long-term liability to the Bristol Bay ecosystem. Furthermore, because the pyritic tailings must remain underwater, they will remain saturated and unstable as long as the facility operates. The FEIS thus cannot rely on a technically implausible closure plan to write off the risk of a pyritic TSF failure. As with the bulk TSF failure analysis, the FEIS should address these potential risks in a meaningful way, as Lynker (2019a, 2019b) has done. This was also recommended by ADNR in its cooperating agency comments:

> For completeness, Dam Safety recommends that the EIS evaluate potential impacts from the failure of the centerline dam during operations for a 1/1000 annual probability of failure with a release volume roughly equivalent to 20% of the stored volume at the time (Azam and Li, 2010), respective published regression equations if appropriate (Rico, et. al., 2007 or other reference), or other rationalized estimates of stage of operation and release volume (ADNR, 2020, p. 7).

Summary

- The pyritic tailings management plan – in which pyritic tailings would be placed back into the open pit – is impracticable, and cannot be used as justification to dismiss the risk of a pyritic tailings facility failure.

Recommendation

- Because the current plan for pyritic tailings management is impracticable, the pyritic tailings plan should be revised in the PFEIS to include perpetual storage of pyritic tailings in the pyritic TSF and consequent environmental risks, as recommended by ADNR.

1.5 The Lynker TSF Failure Model Results are Relevant and Applicable to the FEIS

The FEIS is clear that there are substantial uncertainties in the ability of the "thickened tailings" to drain, and therefore in the ability of the conceptual-level bulk tailings facility design to operate as intended. Given these uncertainties, a complete dismissal of tailings dam failure risk is clearly inappropriate. Despite multiple agencies and public comments requesting that a tailings dam failure analysis be included in the FEIS (USEPA, 2019; ADNR, 2020), USACE chose not to answer these requests. This section summarizes the reasons that the Lynker (2019a) tailings failure model is an appropriate analysis to inform the environmental risks from the Pebble Mine.

Section 4.27.8 of the FEIS discusses tailings releases. Throughout this section, the FEIS refers to the bulk tailings as "thickened" tailings, and cites MEND (2017) to suggest that the tailings deposited into the bulk TSF would not pose a significant risk to the downstream environment, even in the event of a tailings dam failure:

> Previous studies suggest that thickened tailings are capable of flowing approximately 20 times the length of the height of the embankment (MEND 2017),

> depending on topography. In the case of a release from the bulk TSF main embankment, this distance would be about 2.2 miles (FEIS, p. 4.27-96)

The problem with this statement is that it mis-represents the MEND (2017) report, and therefore substantially underestimates how far tailings from the bulk TSF might travel in the event of a release. "Thickened" tailings are described by MEND (2017) as follows:

> High-density thickened/paste tailings facilities involve delivery, in a pipeline, of a high-density thickened or paste tailings (typically ~60 to ~75% solids content by weight and shear yield stresses from 40 Pa to 200 Pa) to the tailings facility. Due to the high shear yield stress of the tailings, positive displacement pumps may be required. (MEND, 2017)

The tailings proposed for the Pebble Mine bulk TSF will be 55% solids by weight, lower than the range quoted by MEND (2017) for "thickened" tailings. Based on available tailings testwork completed by PLP, the yield stress of the bulk tailings at a 55% mass concentration will be less than 15 Pa, and will likely be less than 5 Pa (Figure). Furthermore, other parts of the FEIS state that the bulk tailings "with 55 percent tailings solids and 45 percent contact water, would be expected to flow readily (as a Newtonian fluid)" (FEIS, p. 4.27-108). The bulk tailings described in the FEIS will therefore behave much more like fluid than the "thickened" tailings described in MEND (2017), and would travel substantially further downstream. **The comparison of the bulk tailings to "thickened" tailings described by MEND (2017) is therefore inaccurate, misleading, and inconsistent with other statements within the FEIS.**

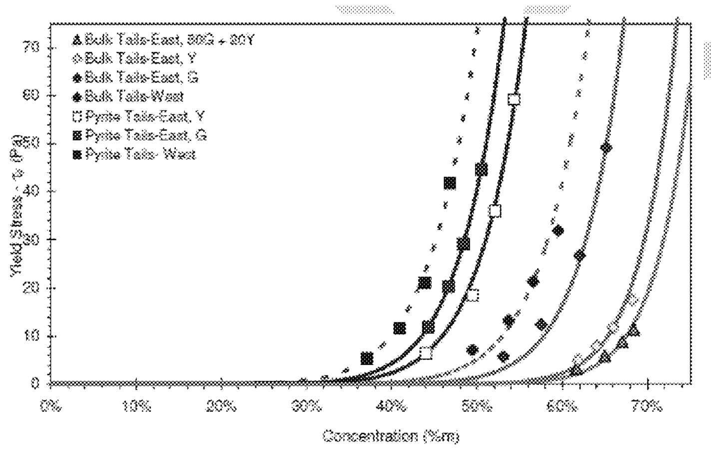

Figure 2. Available tailings testwork from PLP shows that bulk tailings with 55% solids concentration by mass (vertical dashed line) will have a yield stress no higher than 15 Pa (Bulk Tails-West curve) and likely less than 5 Pa (Bulk Tails-East curves). Note that the "Bulk Tails-East, Y" and "Bulk Tails-East, 80G+20Y" would have yield stresses close to zero Source: Figure 2.3 of Knight Piesold (2018a)

Recognizing the need for a detailed, quantitative evaluation of a tailings dam failure for the Pebble Mine, Lynker (2019a) developed a tailings dam failure model using site-specific information regarding site topography, tailings rheology, and tailings solids concentration. All of this information was taken directly from PLP reports or publicly available data. Lynker (2019a) used FLO-2D, an industry-standard model for simulating the tailings releases that has been used by PLP's own consultants (Knight-Piesold, 2014) and that was recommended by AECOM engineers for consideration in the Pebble Mine analysis (Martin, 2018). For model parameters that were either unknown or unknowable, the Lynker (2019a) analysis included a sensitivity analysis to evaluate how model results would change given a range of equally likely scenarios. The Lynker (2019a) model found that even a low-end failure scenario that released only 10% of the bulk tailings would send tailings beyond the model boundary, approximately 50 miles downstream from the bulk TSF north embankment (Figure).

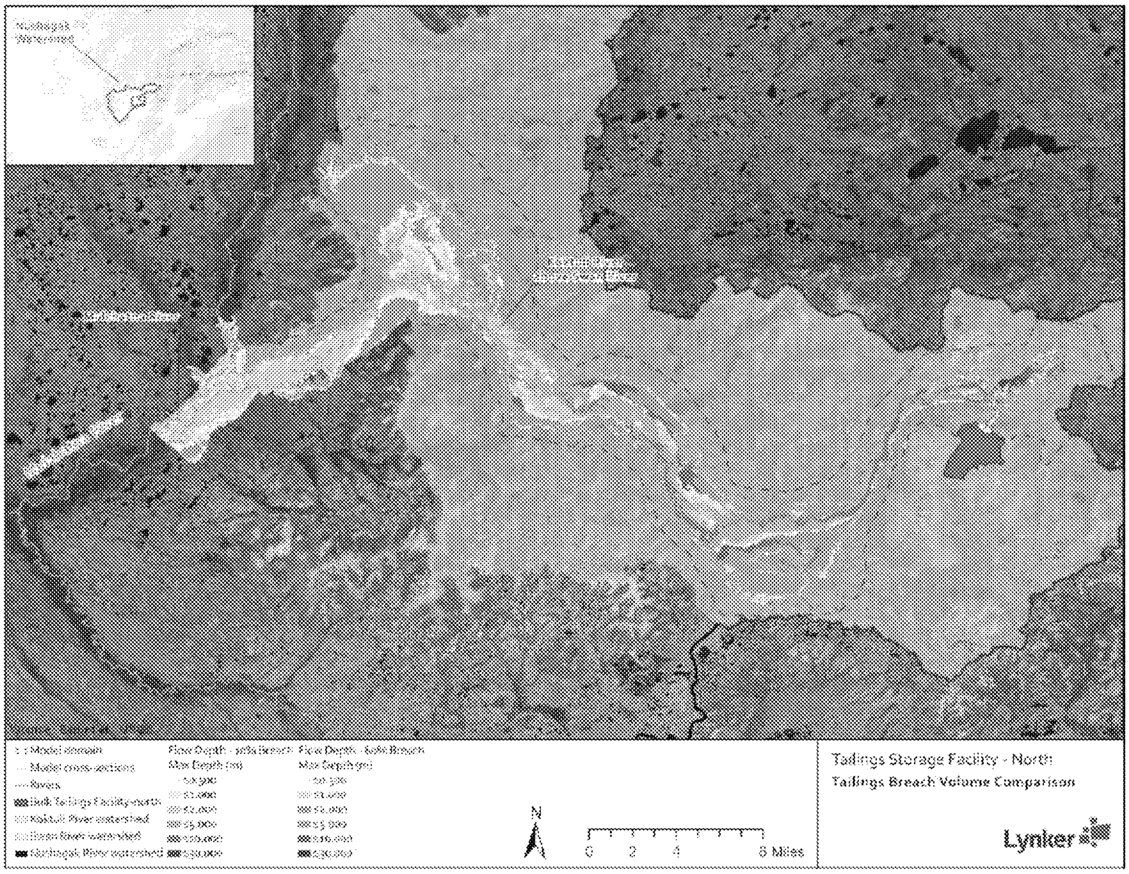

Figure 3. Results of FLO-2D modeling for 10% release (green) and 60% release (orange) from the bulk tailings storage facility. Model domain ends at Koktuli/Mulchatna confluence. Source: Lynker, 2019a.

Appendix K4.27 of the FEIS asserts that the Lynker (2019a) tailings dam failure model is inconsistent with the specifics of the mine plan:

> [the Lynker model] predicted extensive downstream inundation with high volumes of tailings and fluid released in the event of catastrophic dam failures. These models were intended to model failures from the Applicant's proposed mine, but **did not take into account details of the design of the bulk Tailings Storage Facility (TSF), including the use of thickened tailings, water removal plans, dry closure design, and other features described below.** (FEIS, p. K4.27-1)

The Lynker (2019a) model used site-specific data from PLP, extracted from tailings rheology information cited in the draft and final EIS and supporting information contained in RFIs (Knight Piesold, 2018a). This model is therefore relevant to the discussion of tailings dam failure risk from the Pebble Mine, and illustrates the degree of impact that would be expected from a tailings dam failure. If PLP and/or USACE believe that there are inconsistencies between the proposed tailings management plan and the Lynker (2019a) model, then the FEIS should be updated to include its own tailings dam failure model. As summarized above, however, excluding any meaningful analysis of a tailings dam failure by simply dismissing the risk as "extremely low" is not supported by the information in the FEIS.

Summary

- The Lynker (2019a) tailings dam failure model was developed using industry-standard tools and information available from the FEIS regarding tailings properties. It is therefore relevant and applicable to estimating risk from a TSF failure.

Recommendation

- Given that the Lynker (2019a) TSF failure model is the only quantitative model available to document the impacts of such an event, the FEIS should either incorporate its results into the environmental impact analysis for the Pebble Mine, or develop another model that accurately reflects the physical properties of the bulk tailings.

1.6 The FMEA Tailings Spill Modeling in the FEIS is Flawed

Having dismissed the risk of a true tailings dam failure, the FEIS instead considers the downstream impacts of a tailings delivery pipeline rupture due to an earthquake. The tailings volume released by this pipeline rupture scenario is approximately 10,000 times smaller than what would likely be released from a full dam breach (Lynker, 2019a); the analysis thus substantially underestimates the downstream impacts of a tailings failure. In addition, even the analysis of this very minor failure scenario is improper, because it ignores the fluid properties of the tailings as recommended by AECOM's own engineers and is inconsistent with other statements in the FEIS regarding tailings properties.

Section 4.27.8.9 of the FEIS describes the bulk tailings failure scenario as follows:

> The tailings slurry, with 55 percent tailings solids and 45 percent contact water, would be expected to flow readily (as a Newtonian fluid). [...] The slurry would flow downslope as a turbulent flow, with the fine particles of tailings solids remaining in suspension. (FEIS, p. 4.27-108).

This description of the tailings behavior is completely at odds with other parts of the FEIS, which describe the "thickened" tailings as a material that is almost incapable of flow (e.g., FEIS, p. 4.27-96, as summarized above). It is also at odds with communications among the engineers responsible for the risk analysis in the FEIS. As documented in those communications, the tailings release should have been modeled as a non-Newtonian fluid, as in the Lynker (2019a) model. This was recommended by AECOM engineers, but was dismissed by Knight-Piesold due to the rushed timeline of the FEIS process (Martin, 2018)

> *V. Martin, Knight Piesold*: "We do not have a non-Newtonian model currently in place and setting up the model for the tributary may result in a delay to deliver our results on time."
>
> *F. Lan, AECOM*: "There's simple model that's available to model non-Newtonian fluid and FLO-2D is one that I'd recommend."
>
> *V. Martin, Knight Piesold*: "We agree non-Newtonian flows could be modeled in FLO-2D, but developing a new model would result in delays."
>
> *F. Lan, AECOM*: "While the hydraulics can be simplified as a non-Newtonian fluid, I'm not clear how you'll model the TSS down the river."
>
> *V. Martin, Knight Piesold*: "Mixing modeling was not proposed at this time due to a short delivery time."

Summary

- The assumption that the tailings slurry, with 55 percent solids, would "be expected to flow readily" is at odds with other parts of the FEIS that assume the thickened tailings cannot flow, and that are used to minimize the impacts of a tailings dam failure.
- The tailings failure model that was included in the FEIS was demonstrably guided by a rushed timeline, rather than by best available science.

Recommendation

- A full tailings dam breach should be modeled in the FEIS based on available data regarding the bulk tailings properties. The engineers tasked with modeling the existing TSF failure scenario agree that a package like FLO-2D, which can model non-Newtonian flows, should be used for this exercise.

1.7 Summary of Tailings Design Flaws

The FEIS risk analysis with regard to a tailings dam failure is predicated on the assumption that the bulk tailings facility impoundments cannot fail. The FEIS draws its conclusions based on the assumption that the bulk tailings will "remain in place in perpetuity in "dry" closure" (FEIS, p. ES-103), and that the pyritic tailings will be placed into the pit after the 20-year mine life. However, all of the assumptions underlying these conclusions are flawed: PLP has systematically rejected each of the BAT recommendations for safe tailings management; USACE's own engineers question the feasibility of the bulk tailings facility "dry closure" design; and ADNR correctly notes that replacing the pyritic tailings into the pit is impracticable. As a result, the entire risk analysis with respect to the tailings facilities is flawed. Multiple cooperating agencies noted these flaws in the draft EIS and requested that a full tailings dam breach analysis be included, yet none of these concerns were addressed in the final document.

2. The "Comprehensive Water Modeling System" is Flawed and Should not be Used to Predict Hydrologic Impacts of Mining

Groundwater-surface water interactions are a fundamental part of the Bristol Bay ecosystem: groundwater feeds surface water, and in some cases surface flows return to the ground (PLP, 2011). To model the impacts of mining on downstream flows, it is thus critical that the hydrologic modeling system simulate the interactions between shallow aquifers and streams in the baseline, and the changes to those interactions due to burying streams and wetlands, dewatering the open pit, and transferring water between watersheds.

Pebble's "Comprehensive Water Modeling System," comprising the Watershed Model, the groundwater model, and the mine plan model, is the set of tools used in the FEIS to predict the hydrologic impacts of mining (Knight Piesold, 2019a). According to RFI 109g, the Watershed Model "was developed to estimate long-term baseline surface and groundwater flows between sub-catchments within the Watershed Model Area under a wide range of climatic conditions, and to assess the potential effects of the mine on flows downstream of the Mine" whereas "the Groundwater Model simulates groundwater flow rates and groundwater-surface-water interactions, throughout the Groundwater Model Area" (Knight Piesold, 2019a).

This section highlights significant issues with both the Watershed Model and the Groundwater Model, which collectively indicate that any hydrologic predictions from the Comprehensive Water Modeling System are fundamentally flawed. As a result, PLP's system of models should not be used to predict the effects of mining on the hydrologic systems in and around the Pebble Mine. We first show that the lumped-parameter Watershed Model cannot be used to simulate the effects of the mine because it does not simulate any of the physical processes that will be most impacted by mining activities. We then show that the projections from the groundwater model are also flawed because the model does not accurately simulate shallow groundwater, it uses parameters that are inconsistent with available measured data, and it does not include an estimate of model uncertainty.

2.1 The Mine-Impacted Flow Projections in the FEIS are Unreliable

In our previous comments, we noted that there appeared to be issues with the proprietary mine site water balance. Specifically, based on a simple comparison of net precipitation and net streamflow as reported by PLP, there is a significant mis-match between the amount of water PLP has measured coming onto the site as net precipitation (e.g., precipitation minus evapotranspiration) and the amount of water they have measured coming off the site as streamflow. This issue has not been resolved in the FEIS. Furthermore, upon review of the updated Watershed Model report (Knight Piesold, 2019b), it is clear that the issue we raised with the water balance highlights a more important problem – that **the lumped-parameter Watershed Model does not physically simulate the key hydrologic processes that mining would affect, and therefore cannot be used to predict hydrologic impacts of the mine.**

In our comments on the DEIS, we constructed our own simplified water balance to evaluate the accuracy of the proprietary mine site water balance. Using values reported in the DEIS, we highlighted the mismatch between the measured precipitation and the measured streamflow in the site watersheds. Our preliminary conclusion was that

PLP's baseline data either systematically under-measures streamflow, or systematically overestimates precipitation. Those findings are summarized below:

Gage	Area (mi2)	Area (ft2)	Q out (cfs)	Q in (cfs)	Q out/Q in
SK100A	106.92	2.98E+09	259.3	336.3	75.7%
SK100G	5.49	1.53E+08	13.2	17.3	75.3%
NK100A	105.86	2.95E+09	247.2	333.0	73.1%
NK119B	3.97	1.11E+08	4.3	12.5	33.6%
UT100B	86.24	2.40E+09	221.4	271.3	81.4%
UT100E	3.1	8.64E+07	9	9.8	91.3%

Table 1. Drainage areas and average annual flows (Q out) from DEIS, Table 3.16-4. Average annual inflows (Q in) were calculated using average net annual precipitation reported by Knight Piesold, 2018g (42.7 in/yr) multiplied by the drainage area of each watershed and converted to cfs.

RFI 138 provides a response to the criticisms we raised at the DEIS stage, and suggests that we did not account for three factors: 1) orographic effects; 2) a "local precipitation factor" for each sub-catchment; and 3) groundwater exchange. In fact, our simplified water balance did address orographic effects and groundwater exchange: we explicitly noted that the mis-matches in Table 1 are independent of elevation or catchment size, and we drew directly from the DEIS which stated that "the majority of water that recharges the groundwater system in local watersheds generally discharges in the same watersheds" (DEIS, p. 3.17-8). It is point #2 that is most important, as it illustrates the main point of our critique, and also highlights a much larger issue with the Watershed Model.

The Project Hydrometeorology Report describes how precipitation and streamflow data are combined in the Watershed Model, which in turn feeds all of the hydrologic projections contained in the FEIS:

> The orographic and location scaling factors were estimated **by calibrating the Watershed Module to achieve a balance between meteorological inputs and corresponding groundwater and surface water responses.** The resulting spatial distribution of estimated long-term mean annual precipitation in the Project area is presented on Figure 3.6. (Knight Piesold, 2018b)

Put another way, the Watershed Model – which is used to support virtually all of the hydrologic projections in the FEIS – simply adjusts the basin-averaged precipitation values to ensure that there is a match with measured streamflow, on a monthly basis, at the scale of each sub-catchment. This is the nature of the "local precipitation factor" described in point #2 of RFI 138, and it creates a physically implausible patchwork of basin-averaged precipitation inputs, as shown in Figure below.

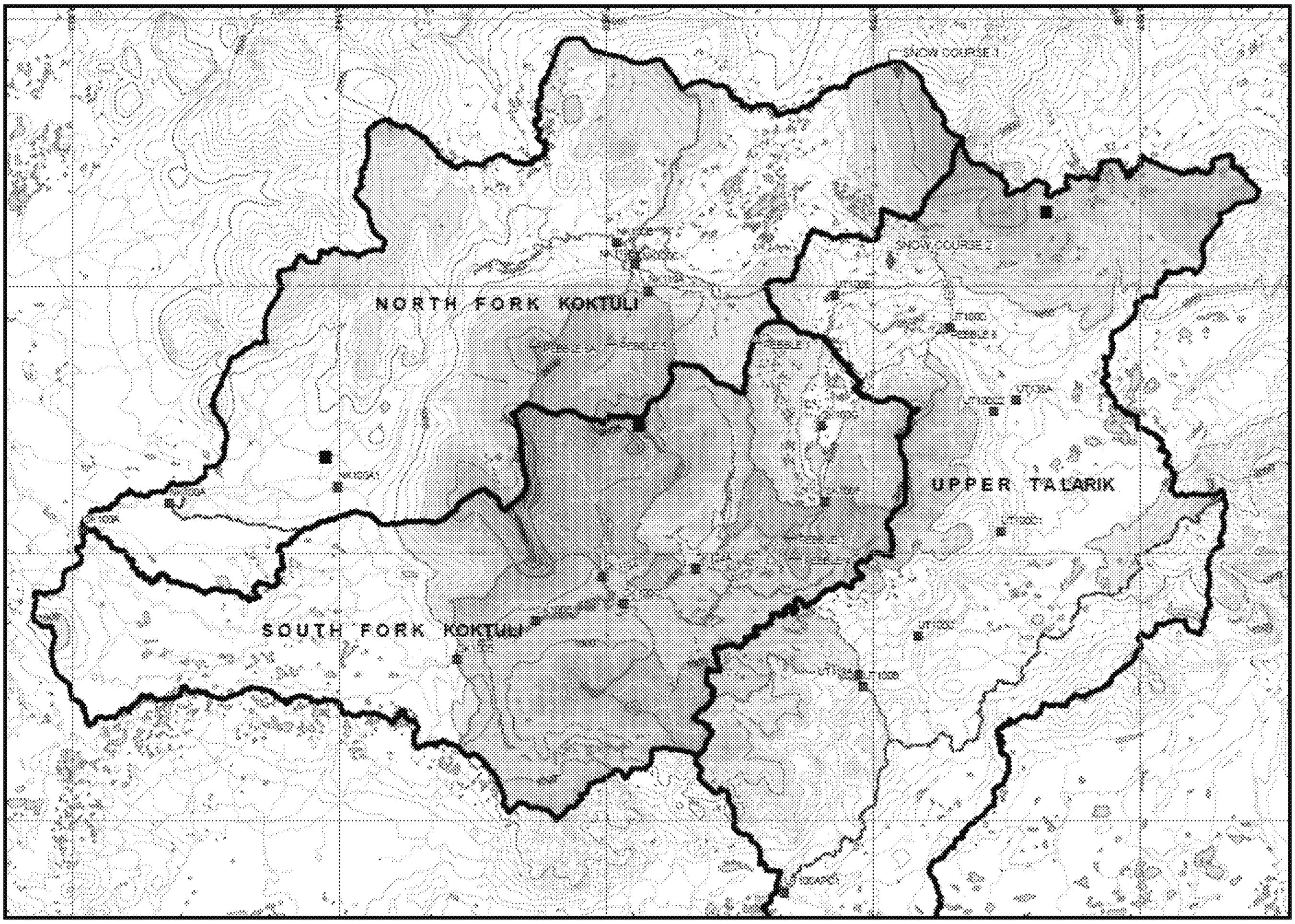

Figure 4. Input precipitation used in Watershed Module. Note sharp breaks in precipitation between sub-catchments, commonly creating artificial jumps in precipitation exceeding 20-30 inches across subcatchment boundaries. Source: Figure 3.6 of KP, 2018a

Note that the precipitation inputs to the Watershed Model are discontinuous, in some cases jumping by 30 inches or more across basin boundaries (e.g., the SK119A vs NK100A1 basins), and in other cases decreasing with elevation rather than increasing, as the orographic factor requires (e.g., SK100F vs SK100C basins) (Figure). This physically implausible distribution of input precipitation is a result of tuning the precipitation in the Watershed Model to match the streamflow measurements – which are the only measured calibration targets for the model. Furthermore, the Watershed Model ignores the spatially distributed, site-specific precipitation records that were collected at 6 stations, at elevations ranging from 800 ft to 2,300 ft, and it relies instead on a synthetic meteorological record generated from the Iliamna airport station – approximately 17 miles southeast of the mine site (Knight Piesold, 2018b) – to drive the watershed module.

In addition to the synthetic precipitation record being implausible, all of the other other hydrologic processes relevant to a water balance (e.g., evapotranspiration (ET), sublimation, infiltration, groundwater storage, and groundwater flow) are represented by lumped parameters, using extremely limited data, and with no calibration or verification. In most cases these lumped parameters are based on arbitrary assumptions or un-referenced equations. For example:

- Snowmelt is parameterized using a simplified "temperature index" equation that is un-referenced, and which includes parameter values that have no supporting documentation (Knight Piesold, 2019b p. 11). Groundwater infiltration is not allowed to occur in the model during summer or winter: "Groundwater recharge is only allowed when evaporation and soil moisture requirements are met.

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Recharge therefore does not occur during the summer when the soil is not fully saturated or in the winter when the ground is covered by snow." (Knight Piesold, 2019b p. 13). In reality, groundwater infiltration can occur at any point in time, and does not require the soil to be fully saturated.

- The soil water balance is calculated using an un-referenced and undocumented equation, which does not account for physical parameters such as root depth, vegetation type, or water table depth (Knight Piesold, 2019b p. 13)
- Soil moisture capacity is arbitrarily assigned to be either 4 inches or 14 inches, but is apparently independent of soil type, vegetation, or water table depth. In reality, soil moisture capacity should depend on all of these physical characteristics, which vary spatially throughout the model domain. As described in the Watershed Model report: "The 14-inch value for higher evaporation areas was somewhat arbitrarily selected to ensure that soil moisture would not limit evapotranspiration losses…" (Knight Piesold, 2019b p. 12).
- Groundwater flow rates are calibrated based on streamflow, rather than using dynamic groundwater elevation measurements or hydraulic conductivity values: " Groundwater storage and flow rates are calibrated primarily using streamflows measured at the site during the low flow season" (Knight Piesold, 2019b p. 15)

Because the Watershed Model uses simplified, lumped, and undocumented parameters to represent virtually every aspect of the hydrologic system, the model is a highly under-constrained system (e.g., Beven and Freer, 2001): there are countless sets of parameters that could produce an equally good fit to the measured streamflow values, many of which would likely do a better job of honoring the measured precipitation on the site. The most significant perturbations to the system due to mining will include removing thousands of acres of wetlands, constructing lined water storage facilities, re-routing precipitation, and capturing groundwater in an open pit. All of these activities will influence evaporation, transpiration, infiltration, and groundwater flow on a very large scale – but none of these processes are physically represented or calibrated to observations in the Watershed Model. As a result, ***the Watershed Model should not be used in a predictive sense to simulate the hydrologic impacts of mining***.

Summary

- The Watershed Model is the basis for all of the hydrologic impact assessments in the FEIS. As such, it must be able to simulate all aspects of the coupled surface water-groundwater system. However, it remains flawed for the following reasons:
    - The input precipitation distribution is arbitrarily adjusted on a catchment-by-catchment basis, leading to an unrealistic patchwork of precipitation inputs that ignores measured meteorological data.
    - Although the Watershed Model report states on multiple occasions that it is calibrated to "groundwater and surface water responses," the model is calibrated to streamflow only. There is no documentation of any efforts to calibrate the model to observed, spatially and temporally distributed measurements of groundwater elevations.
    - The assumptions regarding all other aspects of the hydrologic system (e.g., infiltration, groundwater storage, groundwater flow, evaporation, transpiration) are generally undocumented, unreferenced, and do not vary spatially based on any physical aspects of the system.

Recommendation

- In order to accurately simulate the hydrologic effects of mining, the lumped-parameter, spreadsheet-based Watershed Model should be replaced with a spatially distributed, physical model that can adequately simulate the fully coupled surface water-groundwater system at the Pebble Mine.

2.2 The New Groundwater Model Does Not Support the Conclusions of the FEIS

Between the draft and preliminary final EIS, PLP developed a new groundwater model, which has not been subject to public review and comment. BGC (2019a) describes the new groundwater model and its calibration/validation; and BGC (2019e) summarizes the differences between the original groundwater model and the updated groundwater model.

For the purposes of this EIS, the goal of the groundwater model should be to estimate a range of possible future conditions so that the hydrologic impacts of mining can be evaluated. The groundwater model also should be run at a time step relevant to assessing ecological impacts. The updated groundwater modeling report (BGC 2019a) summarizes these objectives as follows (numbering added for clarity):

> The objectives of the predictive mining operations simulations were to (1) quantify the rate of groundwater extraction at the proposed open pit, (2) estimate seepage rates from the proposed Bulk Tailings Storage Facility (TSF), (3) assess changes in groundwater discharge or baseflow to tributaries of NFK, SFK, and UTC watersheds, and (4) predict changes in groundwater elevation (i.e., drawdown and mounding)

As shown below, the updated groundwater model does not meet any of these objectives. As a result, the projected hydrologic impacts of the mine remain entirely speculative. This section summarizes the key reasons why this is the case.

2.2.1 The Pit Dewatering Estimates are Not Supported by the Groundwater Model

The first stated objective of the groundwater model is to "quantify the rate of groundwater extraction at the proposed open pit." However, the groundwater model is poorly suited to doing this because 1) it is missing key information on fault zone hydraulic conductivity, and 2) the model was run in steady state mode only, and cannot simulate dynamic processes such as pit infilling.

The FEIS highlights the importance of fault zones on the groundwater predictions of the model, noting that "Recharge was found to be a less important parameter than hydraulic conductivity of bedrock or faults on groundwater flow to the pit..." (FEIS, p. 4.17-7). Based on the text of the groundwater modeling report, however, there are no data at all to inform this parameter:

> K data are not available to characterize the faults; therefore, conservatively high and low values of 10^{-5} ft/s and 10^{-10} ft/s, respectively, were assigned to all faults in these scenarios (BGC 2019a, Section 9.2)

The hydraulic conductivity of fault zones was classified as a "Type IV" parameter, meaning that adjustments of these values led to "scenarios where model calibration is relatively unaffected, but model predictions are significantly altered" (BGC 2019a, p. vi). The sensitivity analyses in which the fault zone conductivity was adjusted upward led to a near tripling of the groundwater extraction rate from the open pit – from 960 gpm to 2,600 gpm. Crucially, the "base case" for pit groundwater extraction is nearly identical to the low K fault scenario, suggesting that the modeled pit inflow rate and water treatment needs are both likely to be on the low end of actual needs.

Despite recognizing the sensitivity of the model to fault zone conductivity, and having no data at all to characterize the hydraulic conductivity of faults, the groundwater modeling study does not suggest collecting more data now to fill the gap in fault conductivity data. Instead, it simply suggests starting construction and adapting the water management strategy as needed to react to field conditions:

> Possible negative outcomes from these scenarios (e.g., increased groundwater discharge to the open pit, increased Bulk TSF seepage) should be managed through targeted data collection as the Project progresses, and through effective management of the Bulk TSF during mining operations. (BGC 2019, p. vi)

In other words, the modeling report supporting the FEIS acknowledges that groundwater inflow rates to the open pit and seepage from the TSF are both highly uncertain given the lack of data on fault zone conductivity and tailings properties. Yet ***rather than collecting more information to fill this data gap now, BGC (2019) recommends beginning construction of the mine, collecting more data to determine how bad their modeling assumptions were, and hoping that the water management systems are able to compensate for these uncertainties***. This creates an unnecessary risk to the Bristol Bay ecosystem, given the already substantial water treatment challenges that this mine will create.

Summary

- The rate of groundwater inflow to the pit is highly uncertain due to the lack of data on fault zone hydraulic conductivity. However, rather than gathering data on fault zone hydraulic conductivity or even citing previous studies from similar environments, the FEIS uses a low-end value of groundwater inflow rate and proposes to adaptively manage the problem if this value proves incorrect.
- The FEIS estimates of the amount of time it would take for the open pit to overtop appears to be based on a "back of envelope" calculation using a model that was not developed to simulate transient conditions. Therefore, the time required for the pit to overtop and spill –perhaps the largest long-term environmental liability of the Pebble Mine – remains essentially uncharacterized.

Recommendation

- The FEIS requires more support for its assumptions regarding fault zone hydraulic conductivity. Furthermore, the new groundwater model should be run in transient mode, using best avaliable information regarding fault conductivities and pit infill rates, to support the risk analysis in the FEIS.

2.2.2 The Model Projections of TSF Seepage are Inconsistent with Available Data and Contradict the Tailings "Dry Closure Design" in the FEIS

The second stated objective of the groundwater model is to "estimate seepage rates from the proposed Bulk Tailings Storage Facility." Between the original and updated groundwater models, PLP made a number of significant changes to the model inputs, in some cases without explanation. These changes generate substantial changes in the model predictions; are inconsistent with available data; and directly contradict critical components of the FEIS risk analysis.

As one example, the predicted seepage from the bulk tailings facility changed from 90 gpm in the original groundwater model to 720 gpm in the updated groundwater model, an increase of 800% (BGC, 2019b). The explanation for this change is that the hydraulic conductivity of the bulk tailings was increased by more than an order of magnitude relative to the hydraulic conductivity value used in the previous groundwater modeling effort (BGC, 2019b). The previous modeling effort used a value of 1e-7 ft/s for the bulk tailings conductivity, whereas the updated value is 3e-6 ft/s. However, there is no new data presented in the updated groundwater modeling report to support why this change was made. More importantly, the only data that are available suggest that the lower conductivity value used previously is more appropriate.

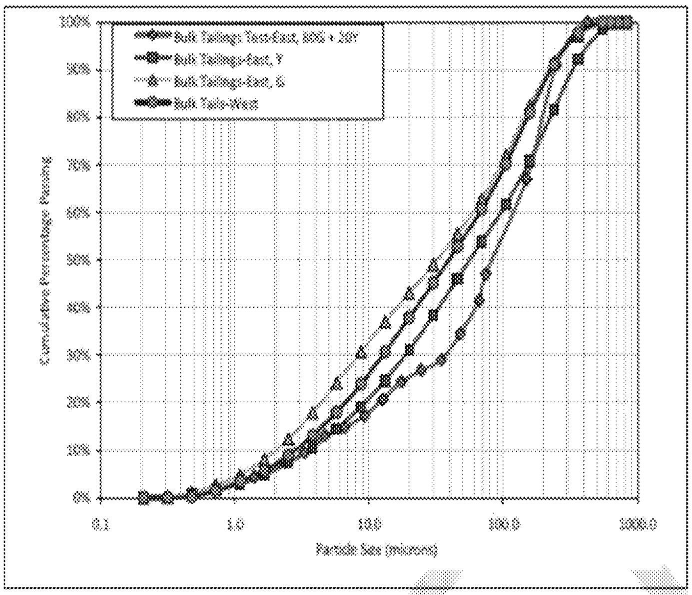

Figure 5. Grain size distribution of bulk tailings. Source: Knight Piesold (2018a).

Knight Piesold (2018a) provides data on the bulk tailings grain size distribution, which to our knowledge is the only dataset available to estimate the hydraulic conductivity of these materials. These data indicate that the 10th percentile of the tailings grain size distribution ranges from approximately 2 to 4 microns, and the 60th percentile of the grain size distribution ranges from approximately 60 to 120 microns

(Figure). Based on these values, we used two empirical relationships to estimate the bulk hydraulic conductivity of the tailings (e.g., Wang et al., 2017). The Hazen equation predicts a bulk hydraulic conductivity of 9.5e-8 to 3.8e-7 ft/s, and the Beyer equation predicts a conductivity of 1.1e-7 to 4.2e-7 ft/s. All of these values are in line with the values used in the previous groundwater modeling effort, and are approximately an order of magnitude lower than the value used in the updated groundwater model.

Thus with no explanation, the hydraulic conductivity of the tailings was increased more than an order of magnitude above the value indicated by available data. Yet even with this artificially high tailings permeability, the groundwater modeling results remain inconsistent with one of the most important conclusions in the FEIS from a risk management perspective: namely, that the bulk tailings will dewater and therefore minimize the risk of a large-scale tailings failure. As shown in Figure below, groundwater mounding in the bulk tailings facility - ***even based on a hydraulic conductivity value that is an order of magnitude too high*** - is estimated to be as high as 400 feet post-closure. Because the post-closure simulation represents steady-state conditions (BGC, 2019a), this means that PLP's own groundwater model predicts the majority of the tailings will be saturated ***in perpetuity***. This modeling output is directly at odds with the "dry closure design" that the FEIS repeatedly invokes to dismiss the long-term risk of a bulk TSF failure (FEIS, p. ES-103; FEIS, p. K4.27-2).

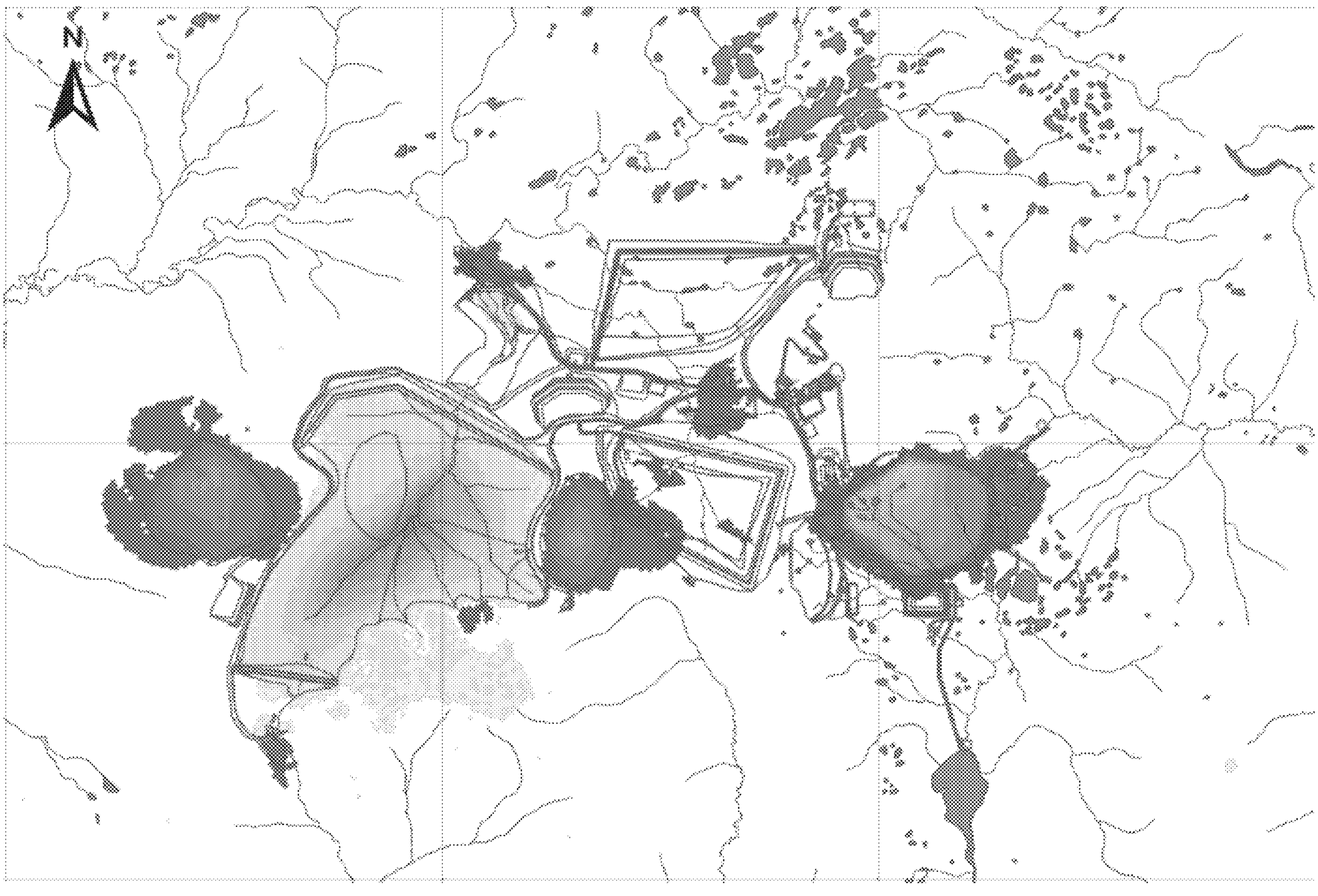

Figure 6. Simulated groundwater mounding post-closure. Note the mounding of approximately 400 ft in the bulk TSF. Since this model was run in steady state only, this indicates that the central part of the bulk TSF will remain water-saturated in perpetuity (Source: BGC 2019, Figure 8-3)

Summary

- The hydraulic conductivity of the bulk tailings was adjusted upward in the new groundwater model by more than an order of magnitude, despite available data that suggests the lower value was more appropriate

- Even with this artificially high conductivity value, the groundwater model does not predict that the bulk tailings will dewater. This directly contradicts the "dry closure design" that is used throughout the FEIS to dismiss the risk of a TSF failure.

Recommendation

- The tailings hydraulic conductivity value used as input to the groundwater model should be consistent with and supported by available data.
- The FEIS should include a more detailed/robust analysis of predictive uncertainty that provides a full range of TSF dewatering responses during operations and post-closure
- If the steady-state groundwater model predicts that the bulk TSF remains saturated post closure, even with a tailings conductivity value that is an order of magnitude too high, the FEIS should not dismiss the risk of a TSF failure by invoking a "dry" closure design.

2.2.3 None of the components of the "Comprehensive Water Modeling System" Simulate Groundwater-Surface Water Interactions

The third and fourth stated objectives of the groundwater model are to "assess changes in groundwater discharge or baseflow to tributaries of NFK, SFK, and UTC watersheds" and "predict changes in groundwater elevation." However, the Groundwater Model also demonstrably misses the mark on being able to accomplish either of these goals.

As one key illustration of this issue, Figure below shows two comparisons between observed and simulated groundwater elevations from the numerical groundwater modeling report (BGC, 2019a). The observed data from these wells are illustrative of how closely groundwater is connected to surface hydrologic processes in this system (Prucha, 2019). Based on the tables provided in the environmental baseline documents, the water table at both of these wells is very close to ground surface: MW-05-12S is at a surface elevation of 1230 ft, and GH04-02 is at an elevation of 1151 ft. Thus, actual (observed) groundwater elevations in both of these wells come within 5 feet of ground surface. Observed groundwater elevations also vary seasonally, rising and falling as much as 10-15 feet with seasonal cycles of precipitation.

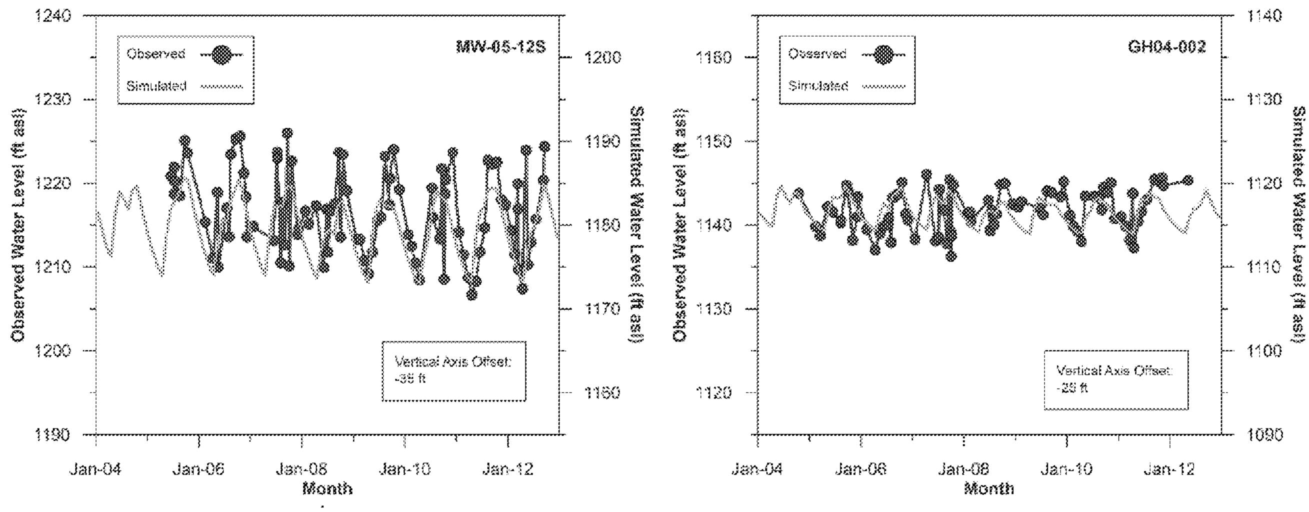

Figure 7. Simulated (green) and observed (blue) groundwater elevations at two wells with observed water levels close to ground surface. Note that simulated water levels are 25-35 ft too deep, as illustrated by vertical axis offsets in both plots. The groundwater model cannot simulate groundwater surface water interactions if simulated heads are 30 feet deeper than observed (Source: BGC 2019a)

At first glance, the groundwater model seems to capture the variability in groundwater elevations at these two wells: the plots were manipulated so that the simulated groundwater elevations (green) overlap with the observations (blue). However, the simulated results have very large vertical offsets, as shown by the secondary yaxes on both plots. Thus, in the example on the left, in locations where the observed water table is near ground surface in the fall (1225 ft on the left axis), the model is simulating a water table that is more than 35 feet too deep (1190 ft on the right axis). This is a critical problem for a model whose purpose is to "simulate groundwater flow rates and groundwater-surface-water interactions" as described above. If the simulated groundwater elevations are 25-35 feet too deep, the groundwater model cannot possibly feed relevant information about groundwater impacts into the broader "Comprehensive Water Modeling System."

Both of the wells shown in Figure are also near the proposed open pit. Since another stated objective of the model is to "quantify the rate of groundwater extraction at the proposed open pit" (BGC, 2019), a model that misses the mark on shallow groundwater elevations by ~30 feet means that these model projections are also flawed. In particular, because it is missing ~30 feet of saturated thickness in the coarse, unconsolidated materials in this area, the model will underestimate the amount of water flowing into the pit, and therefore the pit dewatering and water treatment requirements that cascade through all of the water management decisions described in the FEIS.

Finally, even if the Groundwater Model perfectly simulated near-surface groundwater elevations, there is no mechanism within the "Comprehensive Water Modeling System" for this information to be communicated to the Watershed Model because the mine proponents chose not to use an integrated code. As noted in a response to comments from USACE in August of 2019:

> The Watershed Model and Groundwater Flow Model were independently calibrated to available stream flow measurements; therefore, baseflow predictions were not passed from the Groundwater Flow Model to the Watershed Model for baseline conditions. [...] the non-grid-based Watershed Model, which is structured to target specific areas of mine development and aquatic significance, is used to predict potential impacts to streams in the Project area. The Groundwater Flow Model is well suited to simulate potential impacts to the hydrogeologic system around major mine features and was therefore used to estimate inflows to the Open Pit and seepage under the Bulk TSF (RFI 109g Part 4, p. 27)

Thus, in a region where groundwater-surface water interactions are paramount to ecosystem health and a large open pit mining operation would impact those interactions, the FEIS actually has no integrated system to quantify what those impacts would be.

Summary

- None of the components of the "Comprehensive Water Modeling System" actually simulates the groundwater-surface water interactions that drive ecosystem health in the Bristol Bay headwaters

Recommendation

- In order to understand how mining would affect the hydrology of the Bristol Bay ecosystem, a single integrated model that explicitly tracks all of the elements of this coupled hydrologic system should be developed.

2.2.4 The Groundwater Model "Sensitivity Analysis" Incorrectly Conveys Model Uncertainty

All of the future predictions from a groundwater model will be uncertain, and the range of uncertainty in model outputs will depend on meaningful consideration of ALL sources of uncertainties in the model inputs, including the conceptual model, parameters, assumptions, external inputs, and structural uncertainties. However, rather than evaluating the uncertainty in model predictions, the FEIS and the groundwater modeling report simply describe the results of sensitivity tests, where a somewhat biased subset of selected parameters are adjusted upward and downward within very small ranges relative to their own range of field measurements. These sensitivity tests are primarily focused on 'calibration' sensitivity, and not the vastly more important prediction sensitivity or predictive uncertainty.

> To evaluate model uncertainty, sensitivity analysis simulations of the groundwater model were used to estimate the effects of mine dewatering assuming a range of potential dewatering configurations and aquifer properties. (FEIS, p. 4.17-7)

In modeling, sensitivity analyses are used to evaluate how the model behavior is affected by certain parameters, whereas uncertainty analysis is used to estimate the range of potential outputs based on a reasonable range of inputs. Conflating model uncertainty and model sensitivity, as the FEIS has done, represents a fundamantal lack of understanding of how modeling should be implemented. In this case, using sensitivity analyses as a proxy for uncertainty also substantially underestimates actual uncertainties, as described below.

One example of this is the choice of sensitivity tests for the hydraulic conductivity (permeability) of the unconsolidated materials in the mine area. Field measurements show that the sand and gravel deposits generally have hydraulic conductivity values ranging between 1e-7 to 1e-2 ft/s, or five orders of magnitude (Figure). The calibrated hydrologic model used a value of 2e-3 ft/s for hydraulic conductivity (BGC 2019 Table 6-1), and the model sensitivity tests varied this value upward and downward by one order of magnitude (BGC 2019a Table 9-2). The mean and the range of sensitivity analyses are highlighted by the blue dashed line and blue shading below.

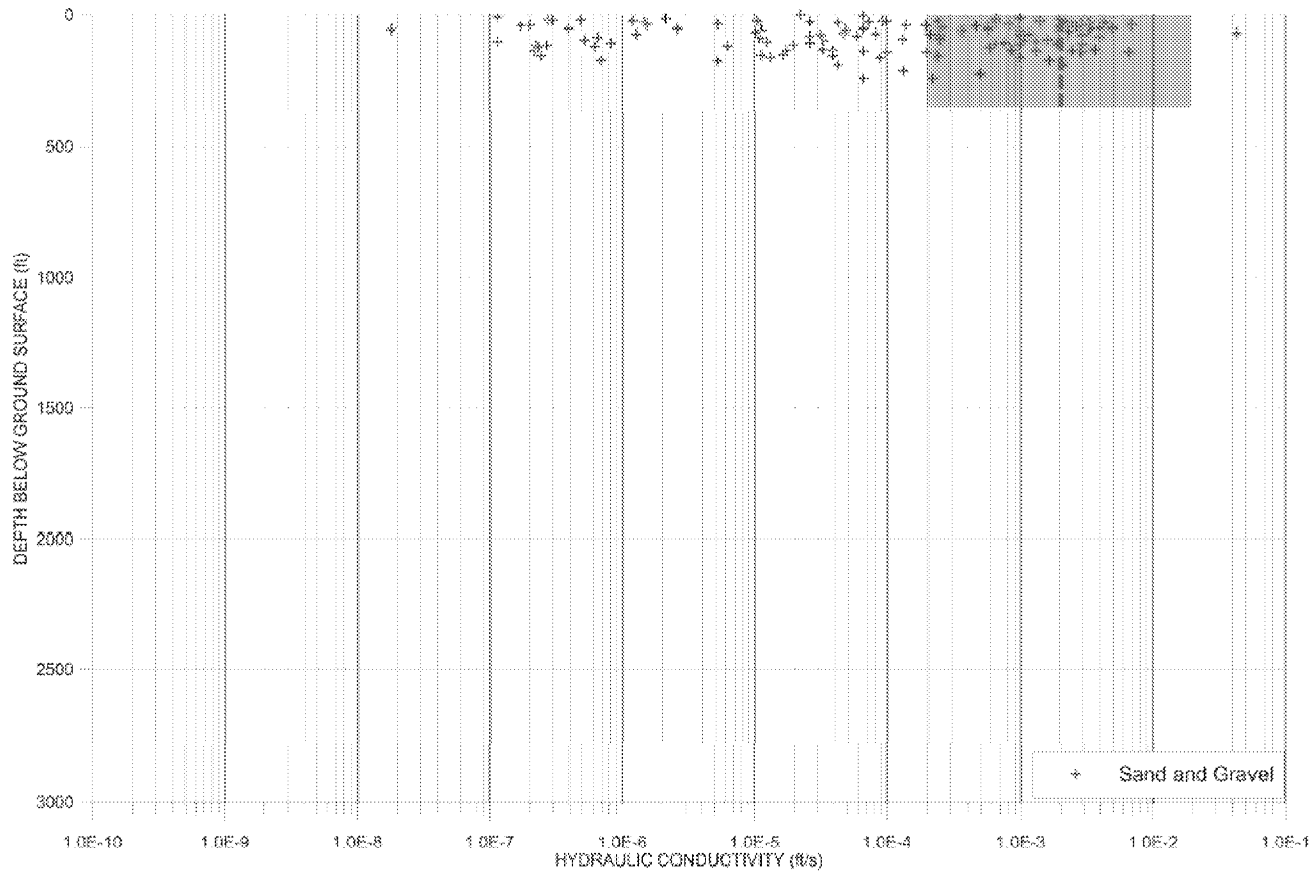

Figure 8. Measured hydraulic conductivity of sands and gravels (red plus signs). The range of values used in the groundwater model is shaded in blue. Note that model sensitivity analyses span just two orders of magnitude, whereas measured values span more than five orders of magnitude (Source: BGC 2019a, Figure A-3)

Figure shows that the "base case" for hydraulic conductivity is near the upper end of values measured in the field, and that the range of sensitivity tests captures only the upper end of measured values. The justification for choosing a base case value of 2e-3 for hydraulic conductivity is that this value produced the best calibration based on the calibration targets chosen (BGC, 2019a). However, as illustrated in Section 2.2.3 above, the calibrated model still remains well off the mark in terms of simulating shallow groundwater conditions, which are among the most important metrics to get right if the model is used to estimate environmental impacts of mining. Furthermore, in complex models typically a wide range of parameter sets exist that can simulate baseline conditions equally well – a concept referred to as equifinality. But while many parameter sets may reproduce baseline conditions equally well, any one of these parameter sets may predict significantly different results once the system is perturbed under future mining conditions. The groundwater modeling report notes that the choice of hydraulic conductivity for unconsolidated materials "results in a significant effect on model predictions but also results in a significant effect on model calibration" (BGC, 2019a, p. v). Since the sensitivity analyses explored only a very narrow range of possible hydraulic conductivity values relative to observations, the ability of the model to predict the effects of mining is questionable.

As shown throughout this section, the model parameters chosen in the groundwater model also tend to paint a more favorable picture of mining impacts than is likely to occur:

- The tailings hydraulic conductivity is biased high, which biases the rate of draining in the bulk TSF upwards but still does not support the "dry" closure design;
- The fault zone hydraulic conductivity is biased low, which generates a "base case" requiring less groundwater pumping than is likely to be required;
- The hydraulic conductivity of the surficial aquifer is at the upper end of observed values, which reduces drawdown in shallow groundwater and minimizes surface water impacts.
- Sensitivity analyses use biased, narrow ranges of adjustments to selected parameters. This not only mis-represents predictive uncertainty, but substantially underestimates the range of equally-valid mining impacts on the surrounding hydrology.

As a result of all of these factors, the groundwater model results systematically minimize the potential hydrologic impacts of mining on the Bristol Bay headwaters.

Summary

- The groundwater modeling report does not provide a range of predictions in model results that reflect the true and comprehensive source of model uncertainty. It also fails to translate model calibration errors into model prediction errors.
- The range of inputs considered in the sensitivity analyses does not fully capture model uncertainty.

Recommendation

- The groundwater model should include a formal uncertainty analysis that feeds into uncertainty regarding the potential environmental impacts described in the FEIS.

3. The Contingencies for Water Treatment Failures are Insufficiently Documented in the FEIS

The mine plan as currently proposed assumes that the mine will be a "zero discharge" facility. In other words, all contaminated water from mine operations will be collected and treated in the water treatment plant before being discharged to the environment. This includes treatment of all contact water that is collected from surface water during mining, as well as all contact water that infiltrates into the ground and travels through groundwater.

> The project would be designed for zero-discharge of untreated contact water during construction, operations, and closure. Water management strategies have been developed to achieve this design and maintain sufficient fresh water for ore processing and other uses at the mine site. (FEIS, p. ES-60)

This assumption underpins the entire analysis of risk for the FEIS. With the exception of Section 4.27 of the FEIS, which describes a limited number of spill scenarios, all of the environmental impacts analyzed in the FEIS assume that this "zero discharge" condition can be maintained. This "zero discharge" assumption carries through into post-closure, as the EIS assumes that perpetual pumping and treatment will ensure that no contaminated waste escapes from the pit lake after closure.

This section summarizes two scenarios that would affect the "zero discharge" assumption, but that are not considered in the FEIS: 1) a failure or abandonment of the perpetual treatment scheme that would cause the open pit to overflow after closure; and 2) a temporary closure of the water treatment plant to allow construction or upgrades in case the conceptual water treatment plans fail.

3.1 Pit overflow

One key part of the "zero discharge" assumption is that the open pit will be pumped and treated in perpetuity after closure, and that this perpetual treatment scheme will never fail:

> The water level in the pit lake would be maintained to create a long-term groundwater sink to prevent pit lake water from discharging to the environment. "Long-term" is defined herein as lasting centuries. Pit lake levels would be managed by pumping and treating water from the lake to maintain the MM level in the pit lake and prevent lake water from discharging into the environment. (FEIS, p. ES-66)

Because the pit water will contain high concentrations of dissolved metals (Lorax, 2018; Maest et al., 2020), this perpetual treatment plan also represents a perpetual liability to the Bristol Bay ecosystem. Specifically, if the pumps fail or if the site becomes abandoned ***at any point in the future***, the pit will overtop and spill contaminated water downstream (Prucha, 2019; Maest et al., 2020). There are a number of reasons that such a scenario should be considered reasonably foreseeable (for example, due to mining company bankruptcy, long-term power failure, earthquake, pandemic, or any number of other potential scenarios). However, these scenarios and their potential impacts are not considered in the FEIS.

3.1.1 The FEIS Does Not Consider a Pit Lake Water Treatment System Failure

Despite the long-term liability of the pit lake overtopping and spilling downstream, this scenario is not considered in the "Spill Risk" chapter of the FEIS. The only clear discussion of the potential for the pit lake to fill and overtop is in the Groundwater Hydrology discussion of Chapter 4, but this discussion is unsupported by any quantitative analysis:

> This amount of water storage [in the open pit] would provide for approximately 1 year of water-level recovery in the event of complete failure of all water pumping for any reason. This is estimated from the rate of water level recovery of the pit lake during late closure conditions, when no pumping of water from the pit lake is planned (FEIS, p. 4.17-15).

This statement in the FEIS is followed by a reference to Appendix K4.17, which then refers back to Chapter 4.17 of the FEIS:

> Section 4.17, Groundwater Hydrology, explains that it would take approximately 1 year for the pit lake to rise 50 feet in the event of complete failure of pumping of water from the pit lake for any reason, and assuming a similar rate of lake-level rise as projected under late-closure conditions. (FEIS, p. K4.17-12)

Based on these statements, there is no analysis to support the statement that overtopping of the pit would take "approximately 1 year." Instead, the contention that it would take one year for the pit to overtop and spill is supported only by a circular reference between Section 4.17 and Appendix K4.17.

The groundwater model is the only tool available that could simulate the rate of pit infilling. However, this model was explicitly not used to estimate how long it might take for the pit to overtop and spill in the case of a perpetual treatment system failure:

> BGC completed steady state simulations only for the post-closure period, and therefore did not generate an estimate of time required for the pit lake to fill or for localized flow to resaturate the bedrock immediately surrounding the pit (BGC, 2019a).

Based on the summary in the FEIS, the contention that it would take "approximately one year" for the pit lake to overtop and spill is apparently unsupported by any data or analysis.

<u>Summary</u>

- A failure of the perpetual pumping and treatment system for the abandoned pit may be the most significant long-term environmental liability of the proposed mine. However, there is no quantitative analysis in the FEIS of how long the pit would take to overtop if the pumps failed, nor of what sorts of contingencies are in place to prevent this from occurring.

Recommendation

- Because of its importance in understanding long-term environmental liabilities posed by the mine, the estimate of pit lake infilling time should be a central part of the FEIS, and must be supported by a robust analysis. Because the groundwater model was run in steady state mode only, a new model capable of dynamic simulations would be required to model the pit lake treatment system failure.

3.1.2 A Pit Lake Overflow Would Create Toxic Conditions in the South Fork Koktuli for More than 30 Miles Downstream

Lorax Environmental (2018) modeled the geochemistry of the pit lake after closure using a simple 1-D model, assuming that the pit lake would remain stratified (i.e., the most dense, ion-rich waters would remain at the bottom of the pit lake and the surface water would be less toxic than the deeper parts of the lake). Maest et al. (2020) conducted a similar modeling exercise using the geochemical code PHREEQC, but allowed the pit to become well-mixed (e.g., assuming the pit waters could overturn via discharge of dense sludges near the surface, landslides from pit walls, or other factors). Both analyses demonstrate that under any realistic scenario, the water quality in the pit lake would be toxic to aquatic life.

The hardness-based water quality standard (WQS) for copper in the South Fork Koktuli drainage is 0.0022 mg/L (Lorax, 2018). Under the assumption that the pit lake remains stratified, the Lorax (2018) model predicts copper concentrations of 0.43 mg/L at 20 years post-closure, and 0.27 mg/L at 105 years post-closure – approximately 100 to 200 times higher than water quality standards. Under the assumption that the pit lake does not remain stratified, Maest et al. (2020) predict a copper concentration of 130 mg/L at closure year 105 – approximately 60,000 times higher than water quality standards. Given these copper concentrations, spillover of water from the pit lake would require dilution of 100-200x (Lorax, 2018) or 60,000x (Maest et al, 2020) in the South Fork Koktuli before water quality became safe for aquatic life.

Maest et al. (2020) used an integrated hydrologic model to estimate downstream impacts of a pit lake overflow, assuming both the stratified pit lake conditions considered by Lorax (2018) and the well-mixed pit lake conditions modeled using PHREEQC. Figure 9 shows the results of these analyses, for a point approximately 35 miles downstream in the South Fork Koktuli. As shown, even under the optimistic assumptions made by Lorax (2018), water quality in the SFK exceeds WQS for copper at this location 35 miles downstream during nearly all months of the year. In the event that the pit lake remains well-mixed, as assumed by Maest et al. (2020), copper concentrations in the SFK exceed WQS by a factor of approximately 1,000.

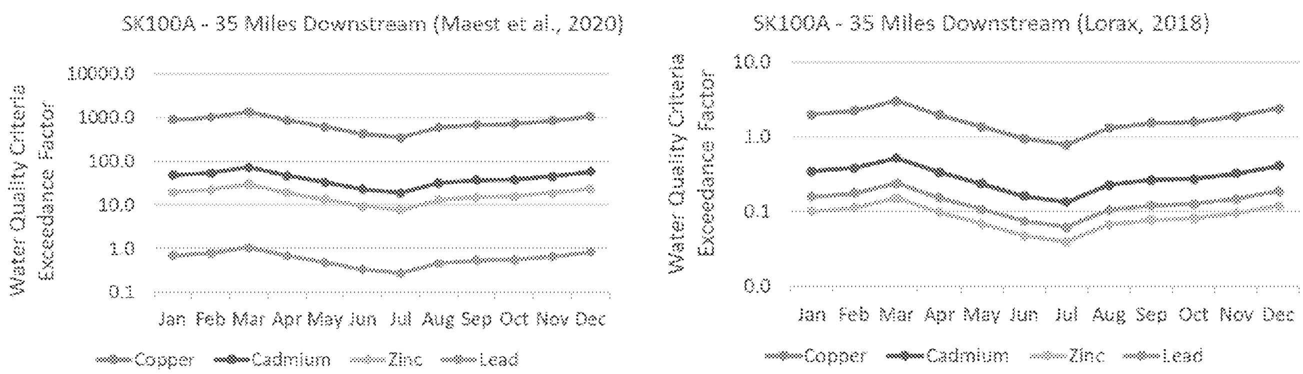

Figure 9. Exceedance factors for four key metals in the SFK ~35 miles downstream from the pit lake assuming a well-mixed pit lake (left) or a stratified pit lake (right). Both cases predict water quality exceedances in the mainstem South Fork Koktuli, but to differing degrees. (Source: Maest et al., 2020)

One of the key conclusions of the EIS – widely cited by PLP, is that "impacts to Bristol Bay salmon are not expected to be measurable" (FEIS, p. 4.24-47). This is true only under the restrictive and optimistic assumption that the mine remains a "zero discharge" facility. An overflow of the pit lake is not considered in this restrictive world, but it is extremely likely to occur at some point in the future given the perpetual treatment scheme being proposed. If it were to occur, copper concentrations would be toxic to aquatic life at least 35 miles downstream even under PLP's own optimistic assumptions of pit lake water quality. Under the more realistic pit lake scenario modeled by Maest et al. (2020), copper concentrations would be toxic for many more miles downstream.

Given that perpetual pumping and treatment is the only mechanism to prevent a spillover of the pit lake from occurring, this failure scenario should be considered reasonably foreseeable: even an event with a very small annual failure probability becomes a near-certainty when integrated in perpetuity. The FEIS completely fails to acknowledge this possibility.

Summary

- The contention that "impacts to Bristol Bay salmon are not expected to be measurable" is only true under the extremely restrictive and optimistic assumptions imposed on the FEIS analysis. As an example, if the perpetual pump/treat system for the pit lake fails at any point in the future, copper concentrations would be toxic to aquatic life at least 35 miles downstream.

Recommendation

- Because a failure of a perpetual treatment scheme is reasonably foreseeable, the FEIS should include analysis of such a failure.

3.2 Storage of water during treatment system upgrades

The FEIS is clear that many systems are in a conceptual design phase – and that finalizing those designs is being postponed until a later date. However, uncertainties in any of these conceptual designs could affect the environmental impact analysis in significant ways. Like the bulk TSF, the water treatment plant (WTP) is also in a conceptual design phase. Recognizing that the WTP may not function as anticipated, the contingency plan for WTP failures is to store excess water in the main water management pond (WMP) while WTP repairs are undertaken:

> As described in HDR (2019g) and PLP (2019-RFI 021h), the WTPs would undergo further investigation as design progresses, and would employ long-term adaptive management strategies. [...] If hydraulic capacity of the WTPs is not adequate to meet the influent flow, additional trains would be installed as needed (PLP 2019-RFI 106). ***The operational capacity of the main WMP provides flexibility (equivalent to 3 average years of water discharge time) to allow time for addressing process interruptions*** (FEIS, p. 4.18-13)
>
> If the treatment strategy proves to be ineffective, modification to the treatment system would be required [...]. the contention is that the water ponds would allow for sufficient storage for up to 3 years of impoundment to allow for implementation of these changes. ***The mitigations are reasonable technical strategies, but the ability to implement such significant changes to the treatment processes within a 3-year period requires further evaluation to determine if engineering and construction can be completed.*** (FEIS, p. K4.18-50)

The remainder of this section summarizes the potential impacts to the downstream environment if WTP upgrades are required, and critically evaluates the assumption that the mine operator would have three years to address these upgrades.

3.2.1 There is Not Enough Storage in the WMP for "Adaptive Management" of Water Treatment Plant Failures

As summarized above, the adaptive management strategy for the water treatment plant relies on having at least three years of storage in the main WMP to ensure that the mine can remain "zero discharge" while WTP upgrades occur. There is no supporting documentation immediately available to back up the contention that three years of storage is available. As summarized below, under normal operations PLP's own data indicates that there is much less storage available.

Figure 3.3 of Knight Piesold (2019e) shows that the median estimate of WTP discharge under normal operations would be approximately 30 cfs. Assuming mass balance, this means that there must be an average of 30 cfs of water entering the WTP requiring treatment, which amounts to approximately 1 billion ft^3 per year (30 cfs * $3.15x10^7$ sec/yr).

Chapter 4.27 summarizes the operational capacity of the main WMP as follows:

> The average volume of anticipated contact water stored in the main WMP would be approximately 1,470 million ft^3, with maximum storage of approximately 2,440 million ft^3 (FEIS, p. 4.27-52)

In other words, under normal operations the WMP would have approximately 1 billion ft^3 (2,440 million ft^3 – 1,470 million ft^3) of available storage – or approximately one year, assuming 30 cfs of inflows – to store wastewater while upgrades to the WTP occurred. After that time, there would be nowhere else to put the waste streams that would continue to require management, unless mining operations ceased and the pit were allowed to flood.

According to Table 4.16-2 of the FEIS, the minimum water storage volume in the WMP would be approximately 300 million ft^3. Even in the optimistic scenario in which a WTP failure occurred when the WMP was at its minimum storage volume, there would still be only ~2100 million ft^3 available (2,440 million ft^3 – 300 million ft^3) – or approximately 2 years of storage. In no case would there be enough storage in the WMP to hold three years of wastewater under normal operating conditions.

Summary

- According to the FEIS, the contingency for a WTP failure is to store wastewater in the main WMP while WTP upgrades occur. The FEIS contends, without support, that there would be three years of available storage in such an eventuality. However, using FEIS values, that number is more likely to be one year, and in no case would it be more than ~2 yrs.
- Given that there is only enough freeboard in the WMP to allow for approximately one year of storage, significant upgrades to the WTP would not be possible during operations without risking a water management failure.

Recommendation

- The water treatment plant design must be well beyond a conceptual design phase before a discharge permit can be granted; "long-term adaptive management" of this system poses too great a risk to the Bristol Bay ecosystem.

3.2.2 "Adaptive Management" of Water Treatment Plant Failures Would Adversely Affect the Downstream Environment in the SFK Drainage

During operations, discharge from the WTP represents a significant fraction of the flow in the upper SFK drainage: shutting off the WTP in order to upgrade the system due to unforeseen issues could therefore significantly alter hydrologic regimes in the river system downstream of the mine.

Under baseline (pre-mine) conditions, average annual flow at SK100F, approximately 3.5 miles downstream of the mine site, is approximately 30 cfs; average annual flow at SK100C, approximately 13 miles downstream of the mine site, is approximately 48 cfs. Thus, the 30 cfs average annual discharge from the wastewater treatment plant represents anywhere from ~60% (at 13 miles downstream) to ~100% (at 3.5 miles) of baseline annual average flows in the upper South Fork Koktuli.

Table K4.16-21 in the FEIS summarizes the changes in streamflow in the SFK downstream of the mine, in the case where no treated water is being discharged back into the stream. Although there are a number of inconsistencies in how these data are presented, we assume here that these projections are accurate, in order to illustrate the impact that shutting off water treatment discharges to allow for WTP upgrades might create. At reach SFK-C at the end of mine operations (corresponding to gage site SK100C), monthly streamflow reductions would range from 0% in March to as much as 80% in January, with an annal average of 12.4%. At reach SFK-D (corresponding to gage site SK100F), monthly streamflow reductions would range from a low of 13.5% in May to a high of 42% in April, with an annual average of 24.3%.

Based on previously published research, hydrologic alterations more than 10% could create "measurable changes in structure and minimal changes in ecosystem functions," whereas reductions of 20% or more have been suggested to create "moderate to major changes in natural structure and ecosystem functions" (Richter et al., 2011). Based on information contained in the FEIS, a shutdown of the WTP would therefore be expected to create moderate to major changes in ecosystem function at least 3.5 miles downstream of the mine site, and measurable changes in structure at least 13 miles downstream of the mine site. While these ecological impacts would be an inevitable outcome of the proposed adaptive management plan to address WTP system failures, such impacts are not described at all in the FEIS.

Summary

- A scenario in which water discharges are completely shut off to allow for WTP upgrades, flow alterations could create moderate to major changes in downstream ecosystem functions.

Recommendation

- Given the current uncertainties in the WTP design, downstream impacts of a WTP failure and associated shutoff of discharges should be considered in the FEIS.

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